



How Can I improve my carbon footprint? What a Nightmare...Ask my anaesthesiologist!

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Abstract. The health sector represents 4.4% of global greenhouse gas emissions. The operating theatre alone is responsible for 40% of these emissions. The three major components of this carbon footprint are: waste production, energy consumption and the emission of anaesthetic gases. The aim of this review is to provide the reader with a range of alternatives available today for the operating theatres, useful to reduce the carbon footprint related to health care activity in this domain. This review illustrates how to apply the 5 R rule: Reduce, Reuse, Recycle, Research and Rethink. In anaesthesia departments and operating theatres, the release of volatile anaesthetics acting as GHGs, the production of considerable medicine waste, the high consumption of energy, all of these are parameters on which it is possible to act to improve the carbon footprint. It is an indisputable testimony to the awareness of the medical world on this subject which concerns us all but also the legacy of future generations.

Key Words: carbon footprint, global greenhouse gas emissions, operating theatre

Improving the hospital's carbon footprint through anaesthesia and the operating room

Introduction

The global rewarming became a huge concern today and a subject of vital interest as the direct and indirect consequences impact the world's population both at the individual level and at the societal level.

The 2023 report of Intergovernmental Panel on Climate Change (IPCC) show an increase in surface temperature of 1°C in 2011-2020 period above 1850-1900 period. This warming is human activity related from greenhouse gases (GHG). Main compounds are carbon dioxide (CO₂) and methane (CH₄) gases followed by nitrous oxide (N₂O), ozone (O₃) and halogenated gases. Since 1750, the CO₂ increases of 47%, the CH₄ of 156% and the N₂O of 23%.

The global climate rewarming has negative consequences on agriculture, on water resource, on the perennity of the biodiversity.

The IPCC has issued proposals to preserve our planet and its inhabitants. A

sustainable development of humanity requires a new sobriety in our consumption of energy and natural resources. For the economies based on ever-increasing consumption, this is a major challenge.

In this context, the health sector is wondering about its role to play in this evolution.

Publications that address this issue are on the rise. According to the Lancet, the health sector represents 4.4% of global greenhouse gas emissions (2). The operating theatre alone is responsible for 40% of these emissions. The three

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major components of this carbon footprint are: waste production, energy consumption and the emission of anaesthetic gases (3).

Based on up-to-date knowledge concerning GHG emissions, the use of consumables, the production and sorting of waste, we describe the most recent initiatives that have been proposed to reduce the environmental impact of these activities essential to the operation of health services, focusing on the operating room.

Methodology

A bibliographic search was carried out on the NCBI PubMed site using the keywords "anaesthesia" and "pollution" over the period from January 1, 2010 to December 31, 2022. The filters applied were Books and Documents, Clinical Trial, Meta -Analysis, Randomized Controlled Trial, Review, Systematic Review, Humans.

A total of 48 articles were identified and analysed. The review then focused on the most recent articles to best describe the current situation of the issue.

Results

The following results show the main factors to consider.

1. Environmental impact of volatile agents

1.1 Atmospheric toxicity of inhaled anaesthetics:

Inhaled agents are widely used in anaesthesia. There are two main families of

anaesthetic or halogenated gases: hydrofluorocarbons (sevoflurane and desflurane) and chlorofluorocarbons (isoflurane and halothane, long abandoned in developed countries). Nitrous oxide (N₂O) is used as an adjuvant to enhance the effect of anaesthetic gases but also alone, for its analgesic and sedative properties. Only 5% of the volume of gas delivered is metabolized by the patient. The remaining, 95%, is directly released into the atmosphere, contributing to global warming. Moreover, the nitrous oxide, has a specific effect on ozone layer as one of the most important ozone-depleting substance. The consequence is destruction of the ozone layer.

Since 2011, we know with good accuracy the global warming potential (GWP) of volatile anaesthetics (4). GWP is a term used to describe the relative potency of a greenhouse gas, considering the length of time it will remain active in the atmosphere. The GWPs currently used are those calculated over 100 years. Carbon dioxide is considered the reference gas and is assigned a GWP of 1 per 100 years (GWP 100). For example, at equal mass, desflurane has a greenhouse effect 2540 times greater than CO₂. This ratio is 298 for N₂O and 130 for sevoflurane.

The toxicity of anaesthetic gases is also expressed considering their atmospheric lifetime and their potential for depletion on the ozone layer (Table 1). To take a more pragmatic view, a 50% mixture of N₂O and oxygen with a fresh gas flow (FGF) of 1L/min emits the equivalent of 15.8 kg of CO₂/h, i.e. the emission of a car driving for 120 km (5).

Agent	Atmospheric lifespan (years)	Radiative potential (W.m-2.ppb-1)	GWP 100	Ozone depletion potential
Nitrous oxide	114	0.00303	298	0,017
Isoflurane	3.2	0.453	510	0.01
Desflurane	14	0.469	2540	0
Sevoflurane	1.1	0.351	130	0

Table 1: Summary of properties of anesthetic gases

1.2 Recent proposals to reduce the environmental footprint of anaesthetic gases.

Replacing a volatile agent with another less polluting is a part of the solution to reduce the carbon footprint of anaesthesia.

A retrospective study analysing 34,097 anaesthesia procedures showed a reduction from 234 tons to 58 tons of carbon dioxide equivalent (eCO₂) if the consumption in N₂O is diminished by 70% (6). Significant gains in eCO₂ have also been reported when desflurane is removed from operating rooms (7).

This data among others that go in the same direction, led to the withdrawal of the use of nitrous oxide and desflurane in many centres.

Reducing the fresh gas flow (FGF) used for the mechanical ventilation is also a manner of limiting the consumption of anaesthetic gas. In current practice, anaesthesiologists are used to work with average flow rates of 2L/min during the maintenance phase of anaesthesia. Following current technological developments, it is possible to work with FGFs of less than 1L/min while maintaining patient's metabolic oxygen needs. This FGF regimen reduces the consumption of anaesthetic gases by half for halogenated gases and makes it possible to reduce by half also the production of GHGs (8).

Unfortunately, sometimes it happens, either through lack of knowledge or through distraction, that the maintenance flow rates are much higher, leading to overconsumption of halogenated agents. The education and awareness of anaesthetists, young and old, to good practices in the use of gases then takes on its full meaning.

Complementary solutions as Centralsorb®, from Blue-Zone Technologies Ltd, have been developed. This is a centralized system, that captures halogenated gases from several operating rooms by filtration before their release into the atmosphere. Anaesthetics gases can then be recovered and processed for recycling. Devices are currently in use in several Canadian hospitals but still awaiting FDA

approval for the reuse of recycled gases. For these reasons, the widespread of these devices is still limited (9).

More recently, The CONTRAfluran™ Anaesthetic Gas Capture System, developed by Baxter, allows the individual recapture (for each ventilator) of exhaled anaesthetic gases. This is a simple-to-install canister gas capture unit which provides sevoflurane and desflurane absorption except nitrous oxide.

In 2020, a photochemical technique for the destruction of anaesthetic gases by UV irradiation was described. Not very active on N₂O (<10% of N₂O destroyed), it is interesting for halogenated compounds (10).

Another study, published in 2015, shows that replacing halogenated anaesthetic gases by propofol or other intravenous or regional anaesthesia techniques (when clinically indicated) would reduce ozone depletion by 3% for laparoscopic hysterectomies and 28% for robotic hysterectomies. (11)

2. Waste management

Healthcare establishments are major producers of waste (e.g. one tonne per hospital bed per year in France) (12). Each operating room can produce up to 2500 kg of waste annually, which means that a single conventional surgical procedure generates, in average, more waste than a family of 4 in a week.

2.1. Reduce: Solid waste

An effective action to improve the environmental footprint of the operating room is therefore to reduce the amount of waste produced. Indeed, during the preparation of surgery tables, it is frequently observed that equipment is decontaminated without being used.

In a study of 52 types of surgeries, Chasseigne et al. highlight a large amount of waste, up to 20% of the budget allocated to equipment (14). In more than 30% of cases, this is because of poor anticipation in the surgeon's real needs. Therefore, the authors propose a "just in time" model for non-urgent surgeries. The surgeon requests the needed equipment to be

opened at the right time, if absent from dedicated pack.

Reducing waste involves optimizing surgical and anaesthetic packs. It regularly happens that an equipment is part of a pack while never used.

In the same way, the creation of a single pack for a type of surgery, in which all the material is sterilized at the same time, avoids the production of packaging that would be generated if each device had to be sterilized separately.

2.2. Reuse: Managing single-use consumables

The first cause of overproduction of waste is linked to the widespread of single-use consumables. The use of disposable devices has spread significantly, initially to respond to concerns about the risk of infections of reusable equipment, and then by their facility of use. However, the WHO has clearly demonstrated that is no difference in terms of infection between disposable and reusable.

It is therefore necessary to consider the environmental impact of both.

The consumption of raw materials and the releases or waste associated with the end of life of a product must be minimized. For this purpose, they must be first quantified.

This is the purpose of Life Cycle Assessment (LCA), an international standardized tool (ISO 14040) that compiles and assesses the inputs, outputs and potential environmental impacts of a product system during its lifetime. LCA is a very useful tool due to its standardisation. The use of LCA by healthcare establishments should be encouraged in order to improve their environmental impact.

This analysis should be considered especially when choosing the medical equipment in surgery/anaesthesia departments.

This crucial choice is often made by people at the top of the hierarchy having primary short-term financial considerations.

The knowledge of the long-term financial impact of the global rewarming and the

use of the LCA as a comparative tool could also lead to a more collegial decisions and improve rationalising ecological initiatives (15).

Several evaluations have compared the LCAs of reusable or single-use materials in operating rooms, such as different types of gowns, laryngeal masks, handles and blades of rigid laryngoscopes, central venous catheter insertion sets or blood pressure cuffs. These rigorous large-scale studies are all in favour of reusable products, with sometimes considerable reductions on environmental impact (16; 17). However, the choice of reusable equipment should not be systematic, but should be based on a strict prior assessment.

CO₂ emissions from disposable products depend mainly on the nature of the energy needed to manufacture them in large numbers, while the carbon footprint of reusable products comes mainly from repeated washing cycles. The ecological footprint of reusable medical devices depends on the number of reuses, on cleaning method (low-level or high-level disinfection), sterilization (steam or ethylene oxide), and the management of waste disposal. (18). Since the economic criterion is also a key parameter in decision-making, it must be estimated correctly without a priori favouring disposable items, which are cheaper to buy and have no maintenance costs. When using reusable laryngoscopes, Sherman et al. showed that in a hospital performing 60,000 intubations per year, the financial savings are between \$675,000 and \$869,000, depending on cleaning method (disinfection or sterilization) (19).

Conversely, the loss of reusable equipment can have significant environmental and financial consequences.

To guarantee the sterility of reused equipment, criteria for use and adequate circuits must be rigorously defined, based for example on WHO recommendations.

Thus, non-invasive devices in contact with intact skin, such as blood pressure cuffs and stethoscopes, can be reused after simple cleaning.

Semi-invasive devices, in contact with mucous membranes or body fluids (e.g., laryngoscope blades, masks, etc.) require a high level of disinfection before being reused (20). Maintaining asepsis of anaesthesia breathing circuits requires weekly washing or renewal and adequate filter usage (21, 22).

2.3 Recycling: Optimizing waste sorting and recycling

Conventionally, waste from healthcare establishments is classified as following:

first, the hospital waste assimilated to household waste (WAHW) and secondly, the waste issued from infectious risk healthcare activities (WIIRHA). The latter are considered hazardous and are divided into chemical, infectious or radioactive waste.

According to the WHO (23), only 15% of our waste is hazardous, and belongs to the WIIRHA category. The remaining 85% is non-hazardous and therefore potentially recyclable.

In real life in the operating room, the WIIRHA are overvalued due to poor sorting practices or excessive precaution, which reduces recycling and increases disposal costs. They require treatments 5 to 6 times more expensive than WAHW with highly energy expenditure (13).

Pedagogical demonstrations of sorting in the field can significantly reduce the volumes of WIIRHA (13) and improve costs.

The reorganization of waste collection carried out at the Institut Marie Curie in Paris, resulted in a 20 to 50% reduction of WIIRHA in 6 months and an eCO₂ saving of 7.6 t (24).

The education of young doctors and nurses in training to the problem of sorting and recycling waste of healthcare activities, could also be very beneficial (15).

There is another advantage of appropriate segregation of waste on the field: to better guarantee the protection of the people who handle it (15).

Anaesthesiologists generate up to 25% of operating room waste, 40 to 60% would be recyclable. According to a prospective audit carried out in Melbourne on six operating theatres, 23% of the waste is recyclable, 45% is to be evacuated in WAHW and 32% only is WIIRHA (15).

In a Belgian academic hospital (900 hospital beds) the annual waste production was similar (table 2, Hospital annual waste production and costs, 2018).

Type of Waste	tons/year	Amount in €/year	% of global cost	% of total weight
PMD	10	7500	1,3	0,5
Papers	102	7140	1,3	5,3
Cardboard	207	6210	1,1	10,8
WAHW	1228	245600	44,9	64,2
Non-contaminated glass	1,7	646	0,1	0,1
WIIRHA	363,5	292400	52,3	19

1912
tons/year **559500 €/year**

Table 2: 2018 Hospital annual waste production and costs

Increasing the fraction of recyclable waste could go through the development of facilities that recycle medical glass or metals

recovered from operating theatres (e.g. "Les Petits Doudous", a charitable initiative in France) (13).

2.4 Medication management

A recent study in an American hospital assessed the extent of wastage of drugs used in anaesthesia field, including propofol (25).

All these drugs have a harmful effect on the environment. This effect may be assessed individually, using the PBT index (Persistent, Bioaccumulative and Toxic) which rate from 0 to 9. The PBT index is related to substances that have a high persistence in the environment (resistance to degradation), a high mobility and a high toxicity.

For example, propofol has a PBT index of 9, fentanyl has a PBT index of 8, ondansetron has a PBT index of 6 (26).

Directly related to anaesthesia, propofol is one of the most detrimental drugs because of its high bioaccumulation and direct toxicity on aquatic organisms. It has a lipophilic structure, is not biodegradable and needs incineration for complete destruction. Barbariol et al, in a prospective observational multicentric study including 12 hospitals in northern Italy during March 2018, found an overall mean wastage rate of 38% with a total financial cost of €78,060. The annually estimated amount of propofol wastage was of 158 liters (34). Another work published in 2019 showed the importance of pollution related to anaesthesia drugs (27). Following these reports, it must be concluded that better medication management in the operating room is mandatory to minimise wastage.

One strategy is to use only the smallest vials of propofol (20 mL) (15). Another strategy involves the use of ready pre-filled syringes or the packaging in sterile syringes from large vials by the pharmacist. For expensive and frequently use drugs (e.g. sugammadex, dexmedetomidine), this is an excellent choice that have been recently demonstrated (9).

2.5 Potential impact of anaesthesia products on the aquatic environment

Water pollution by the most used drugs (oral contraceptives, antihypertensives,

antibiotics, antiepileptics, antidepressants and analgesics) is well documented (28) and many of these molecules or their metabolites are recognized as potential endocrine disruptors, neurotoxicants, mutagens or carcinogens. (29).

In anaesthesia, propofol has the highest PTB index of 9, related to its strong aquatic ecotoxicity on a variety of plant and animal species. Contamination of surface waters by propofol has not been rigorously assessed, but it is clearly a threat due to the huge amount rejected or wasted (the second most administered drug by mass in anaesthesia), to high potential of bioaccumulation and high mobility in soils (29).

The effects on the aquatic environment of chronic exposure to low doses of other leading drugs in anaesthesia, such as cefazolin, acetaminophen, sugammadex, lidocaine, muscle relaxants, opioids, paracetamol, have not been evaluated yet and justify continuing research.

3. Energy and Water

The energy expenditure of a hospital is very high. One of the most energy consuming place inside the hospital, is the operating theatre whose needs are 3 to 6 times more by square meter than the other areas. This is explained in part by the strict requirements concerning air quality and temperature regulation during surgery (9).

To reduce this energy expenditure, several solutions have been proposed: replace lighting with light-emitting diodes (LEDs) and low-mercury lamps; rationalize the use of electricity in case of unoccupied operating rooms (up to 40% of the time in some theatres).

Air conditioning, ventilation and/or heating may be limited when operating rooms are closed. It has been shown, for example, that stopping the ventilation of the unoccupied operating theatre during the night does not lead to an increase in microbiological contamination (18).

Drinking water is a vital resource whose management must be strictly optimized, especially if shortage. Several proposals in this

direction have been made to reduce water consumption and improve the ecological impact associated with its use.

The replacement of plastic water bottles with a water fountain providing filtered water and the use of recyclable water bottles may significantly reduce the ecological footprint and potable water wastage (13). Also, you can reduce the amount of water expended for handwashing by performing handwashing with sensor taps and afterwards using hydro-alcoholic solutions in case of hands are not soiled (18).

A difficult trade-off must also be made between the use of reusable devices that require water for cleaning and single-use devices (31).

4. Discussion

The aim of this review is to provide the reader with a range of alternatives available today for the operating theatres, useful to reduce the carbon footprint related to health care activity in this domain.

This review illustrates how to apply the 3 R rule (Reduce, Reuse, Recycle) based on existing literature. We haven't covered in this review the other existing 2 R rules: Research and Rethink (figure 1).

We need more specific research on the environmental effects of human healthcare-related activities, on life cycle assessment of materials, on cost-benefit comparative studies.

Further research and developments of materials with lower environmental impact is a necessity for our profession. It is obvious that the global reduction in hospital's carbon footprint and particularly in the operating theatre, does not mean any compromise with the quality of the health care. It is also essential to rethink and reorganise our practice starting from the ground and even challenging the pertinence of some of our acts, examinations or interventions.

Education of healthcare providers, awareness of problems related to their activity, continuing information and feedback is also an essential axis for changing mentality.

More, integrating environmental standards into hospital functioning and in accreditation requirements would facilitate the development of greener practices.

We have not mentioned the multitude of obstacles, that prevent the change towards a greener medicine. It ranges from the administrative complexity of healthcare institutions, the lack of support from decision-making responsible to the human resistance to change.

To facilitate the development and implementation of projects on greening the operating theatre, multidisciplinary teams must be formed, including all categories of healthcare providers. These lead to transverse actions which provide synergic effects on a larger scale and a bigger impact.

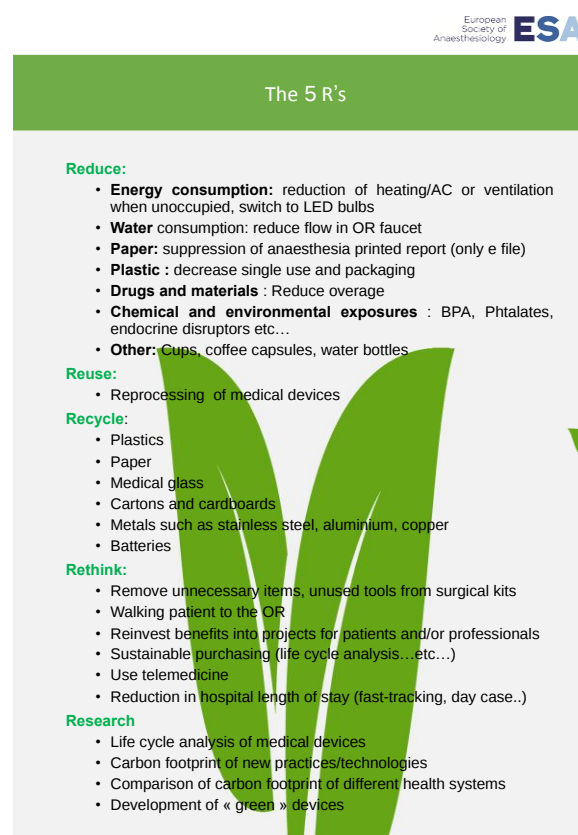


Figure 1: The 5 R's in OR (from ESA, European Society of Anaesthesiology)

5. Conclusion

According to the work of the Intergovernmental Panel on Climate Change, the climate crisis linked to the production of GHGs by human activities is the most significant and longest-lasting threat to global health ever described (1).

In this context, the health system constitutes a paradox. By destination, it must deal with the consequences of climate change on human health. At the same time is an important actor which contributes itself, in a substantial way, to the upheaval of the climate whose effects he combats. It is therefore essential for the medical system to work to preserve a better environment preservation and to act against global warming (15).

In anaesthesia departments and operating theatres, the release of volatile anaesthetics acting as GHGs, the production of considerable medicine waste, the high consumption of energy, all of these are parameters on which it is possible to act to improve the carbon footprint.

The current literature shows a spectacular growing up in number of publications related to this matter.

It is an indisputable testimony to the awareness of the medical world on this subject which concerns us all but also the legacy of future generations.

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